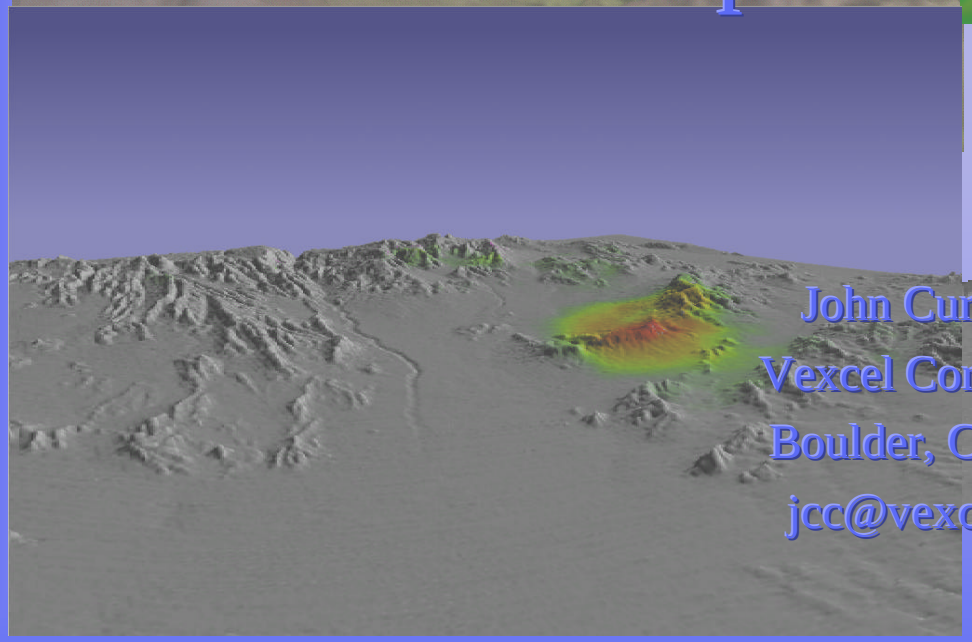
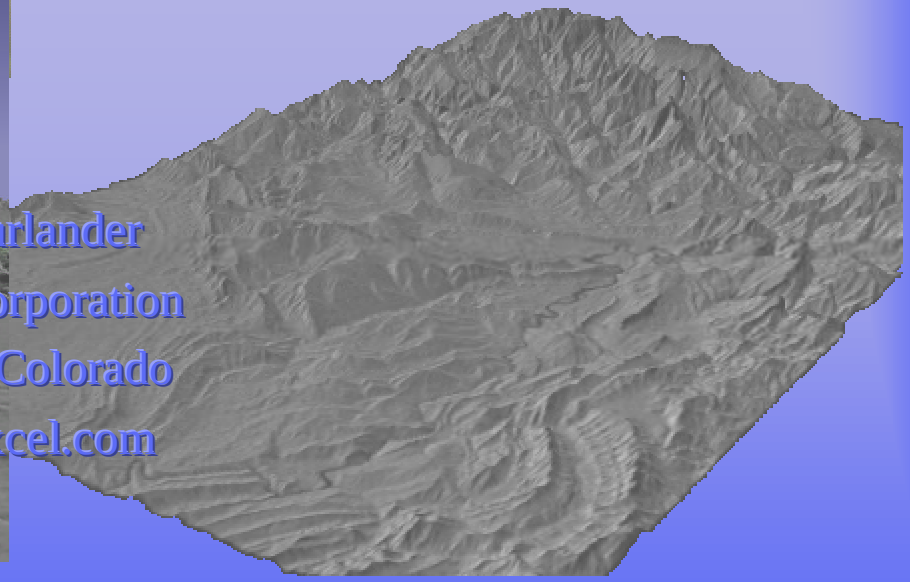
Stereo Radar DEMs
Examples and Results





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Vexcel's Stereo SAR DEM generation

- Stereo SAR methodology and characteristics
- DEM case study – Southern Colombia
- Other examples and IFSAR comparisons
- Techniques
  - Improved DEM and Contour quality
- Conclusions & discussion

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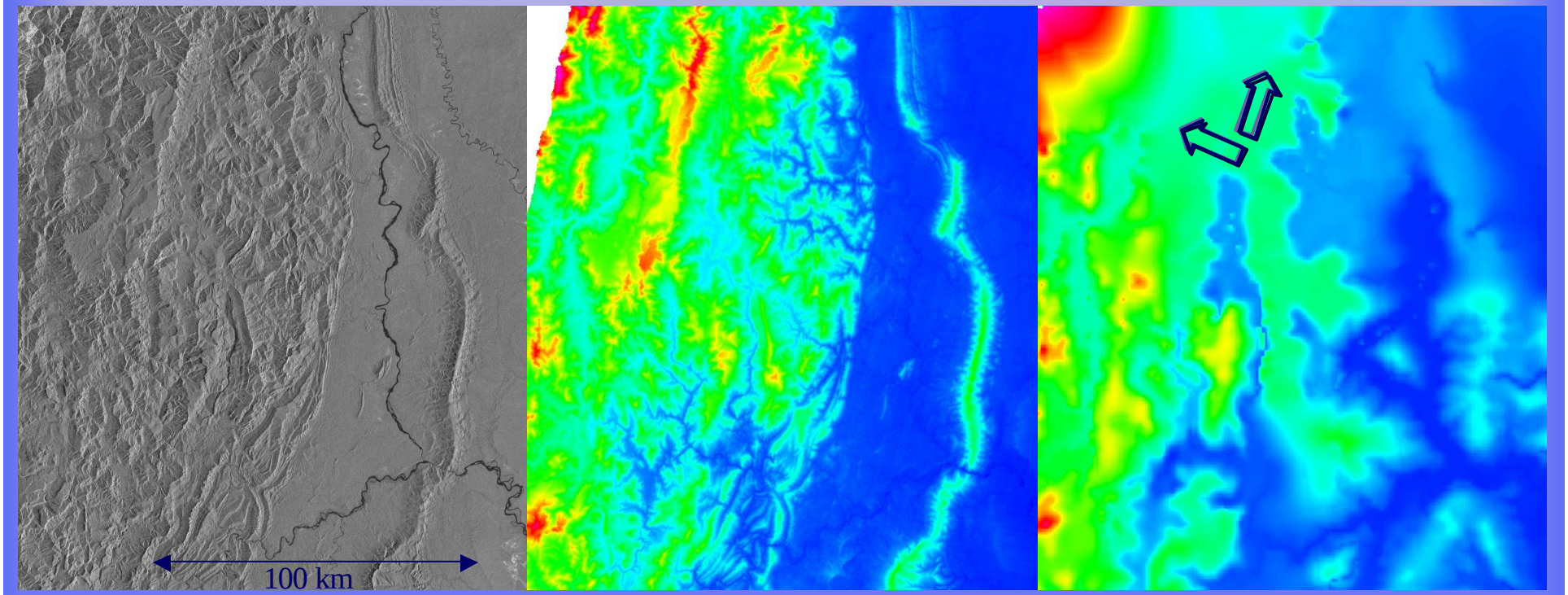
SAR DEM vs. Global Topo Motivation

SAR Mosaic | *RSAT Stereo DEM Mosaic* | *GTOPO-30 arc sec DEM*



- ***3000m high and 100km long ridges missing in global topo map!***
- ***SAR DEMs are complete***
- ***Can be generated based on crude global (median difference = 1m)***

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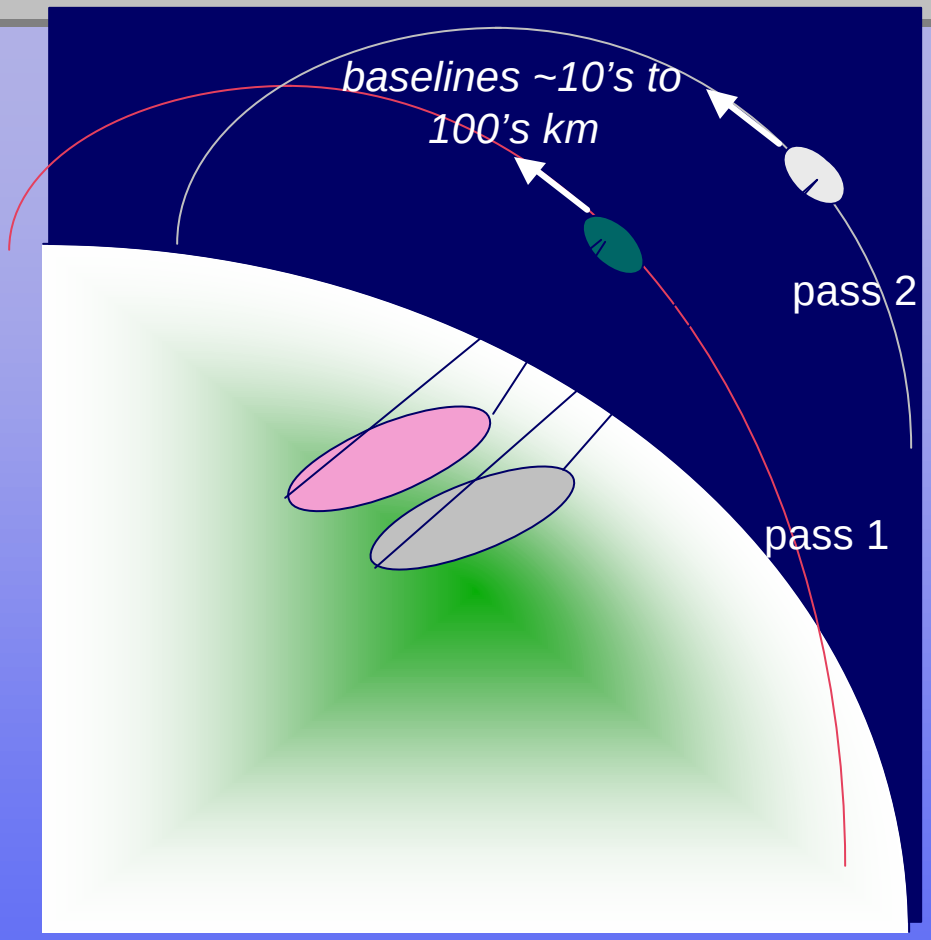
Stereo Radar Overview

Stereo mapping views the same area from significantly different perspectives to obtain a stereo parallax. Reasonable parallax angles range from about 3 to 20 degrees for Radarsat-1.

Radarsat-1 is currently the only spaceborne SAR capable of providing data in this geometry.

Not as precise as Interferometry but generally more reliable than repeat pass IFSAR (stereo is not dependent on phase coherence).



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RADARSAT Stereo Accuracy and Cost Guidelines

	ScanSAR Narrow	*Standard/Wide*	*Fine*
Nominal image resolution	50m	25m	8m
Image swath width	300km	100km	50km
DEM posting interval	150-200m	50m	40m
RMS vertical DEM error	40-50m	20-25m	15-20m
DEM production $/km2	$0.15-$0.25	~~$1.00 -$2.00~~ **$0.40-$1.00**	~~$4.00 - $6.00~~ $2.00-$4.00
SAR data costs $/km2	$0.10-$0.15	~~$1.00 -$2.00~~ **$0.25-$0.75**	~~$4.50-$5.50~~ $1.00-$4.00
Minimum project area	60,000km2	7,000km2	1,750km2

- Standard beam offers balanced cost and accuracy
- Costs vary depending on coverage efficiency and project size.
- Accuracy can degrade for extremely rugged or featureless terrain.

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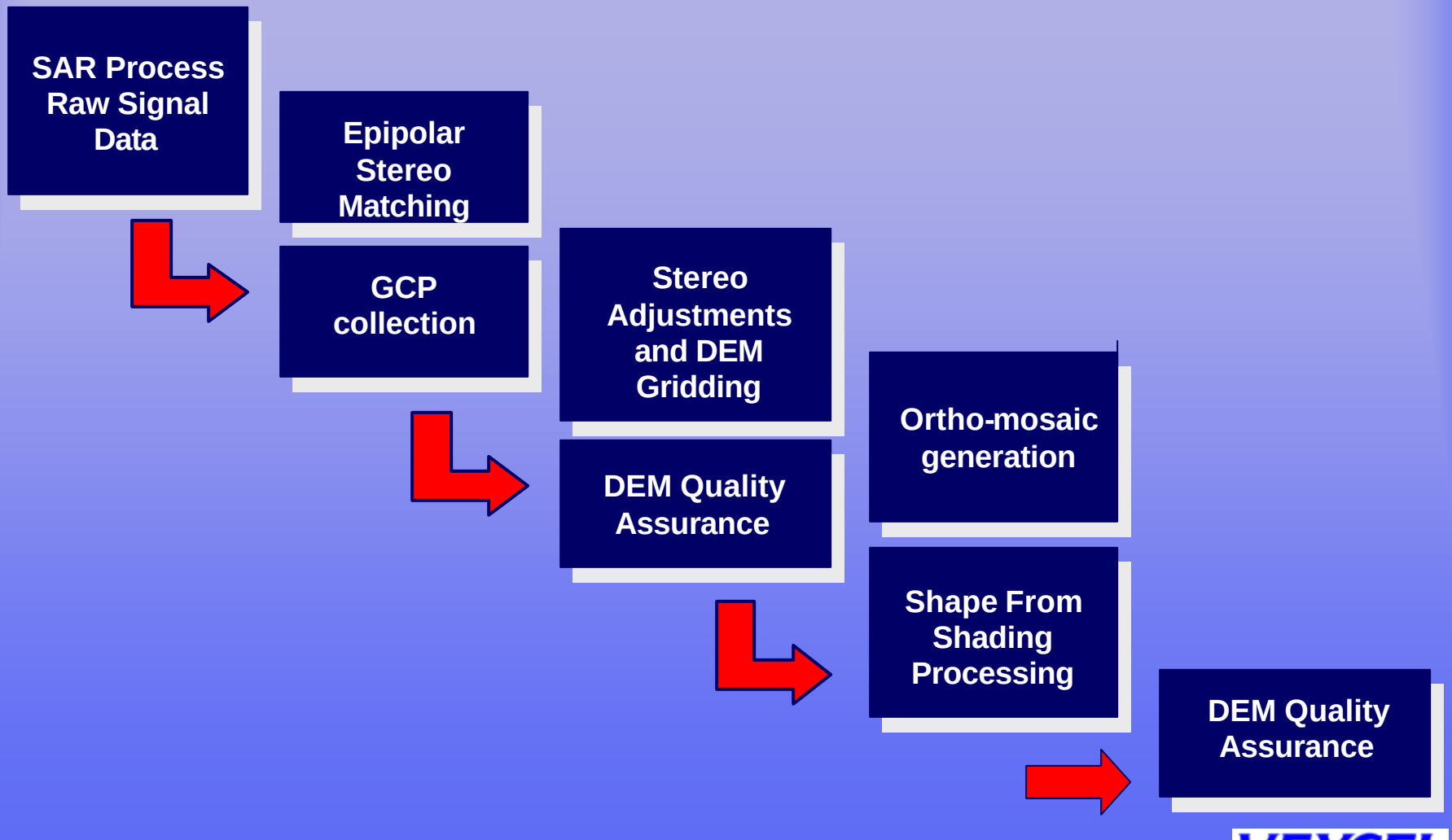
Stereo Production Process Flow



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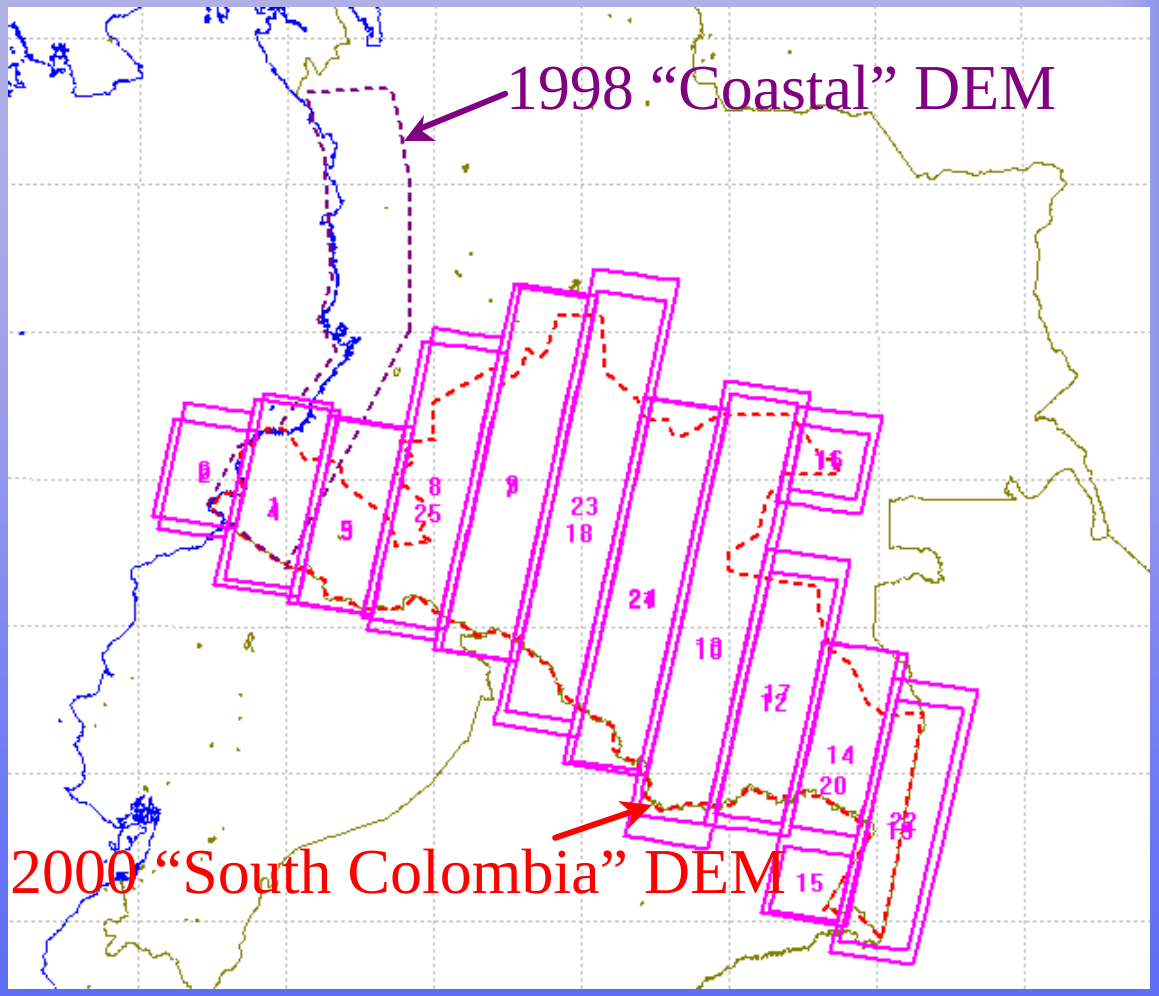
Southern Colombia RADARSAT Stereo Project

- NIMA AOI: 370,000km^2
- RADARSAT stereo coverage: +500,000km^2
- 33 Standard/Wide beam stereo pairs
- 50m DEM with RMSE 25-30m, 25m ORI
- Utilize archived RSAT coverage and new acqs
- Delivered 4 months from Order, 1 month after GCP collection completed



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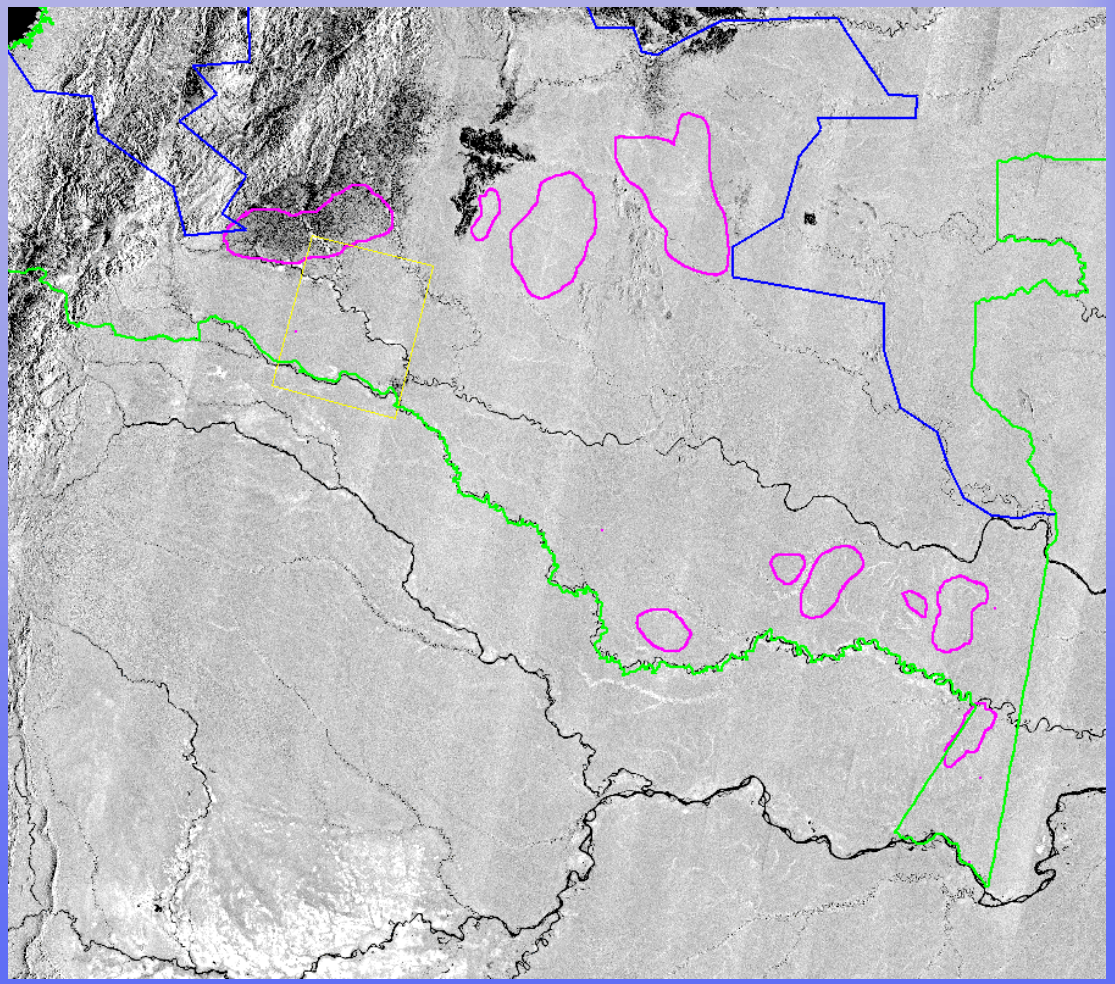
NIMA Southern Colombia RADARSAT Stereo Project

- Archived SAR mosaic images used to predict featureless areas before acquisition
- Shape From Shading applied to entire area for improved detail and to eliminate stereo voids
- Ground truth:
  - 100+ check points
  - 87 GCPs spanning AOI



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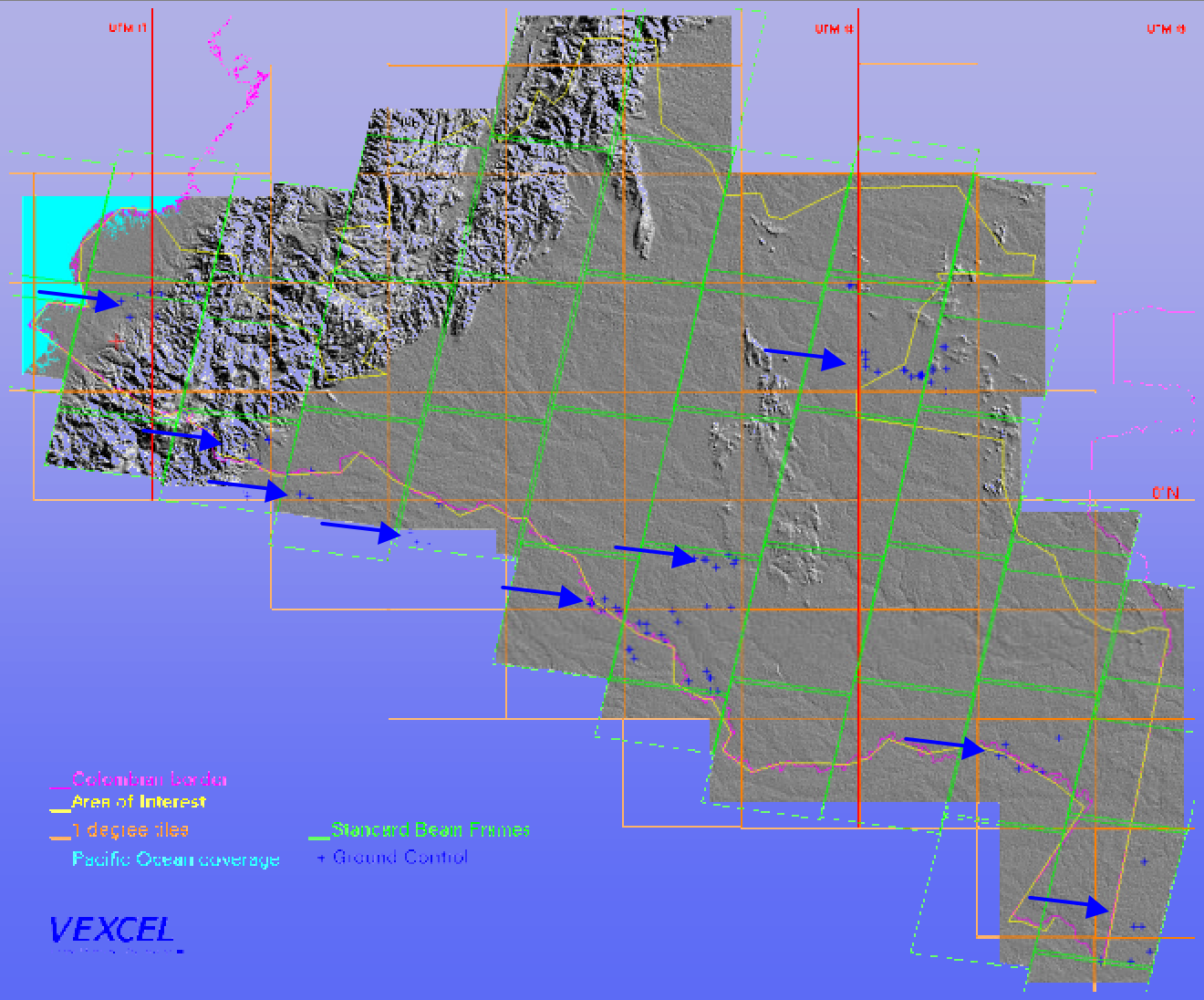
South Colombia Coverage



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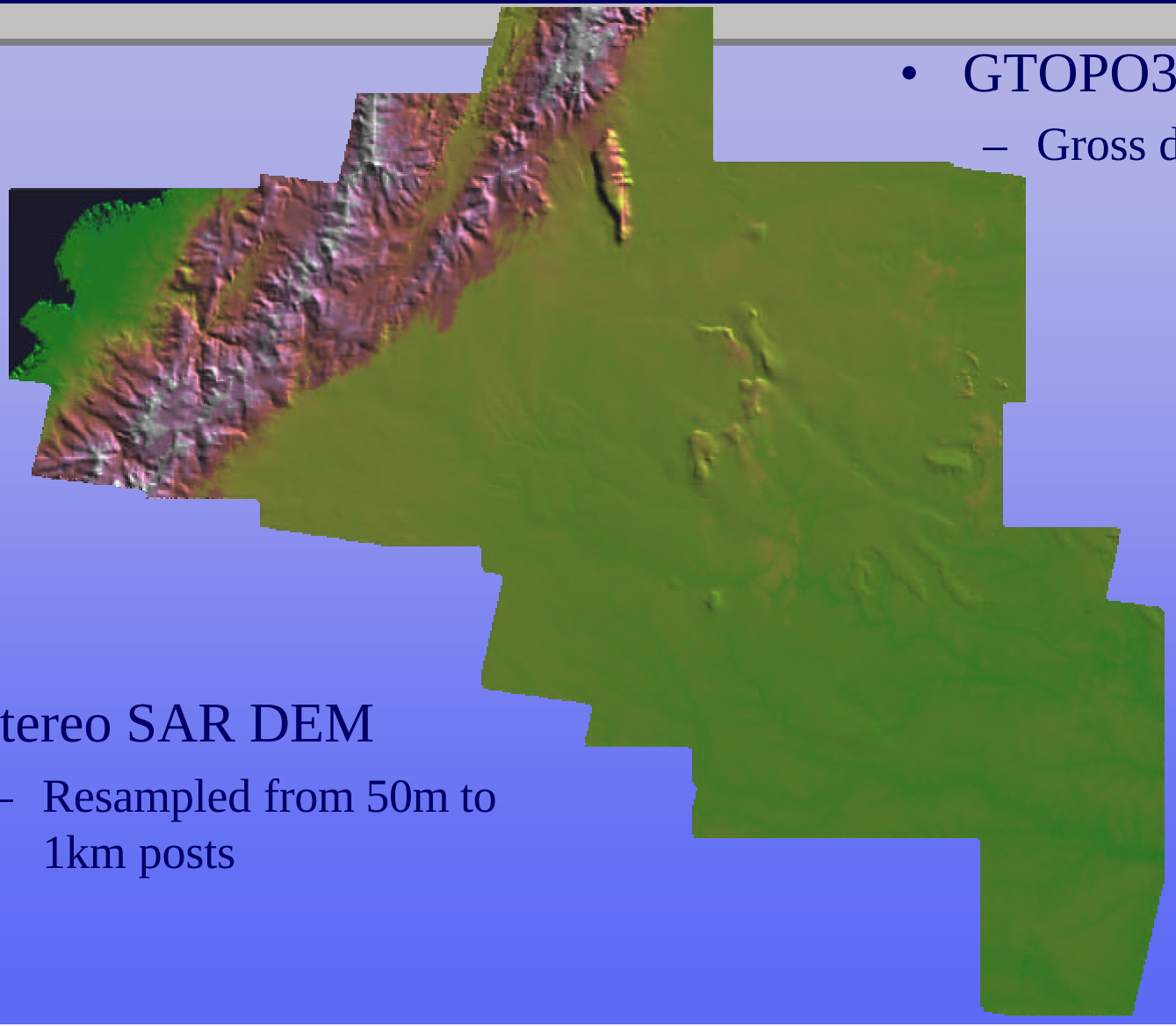
SAR DEM vs Global Topo
South Colombia



- GTOPO30 DEM
  - Gross distortions

- Stereo SAR DEM
  - Resampled from 50m to 1km posts

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RADARSAT South Colombia DEM Validation Summary

Summary Statistics of Elevation Error

Both Sources:

- Mean = 5.0
- RMSE = 28.9
- Sigma = 28.5 N = 211

GCPs only:

- Mean= 18.6
- RMSE= 27.5
- Sigma= 20.4 N= 87

Checkpoints only:

- Mean= -4.94306
- RMSE= 29.8
- Sigma= 29.4 N= 124

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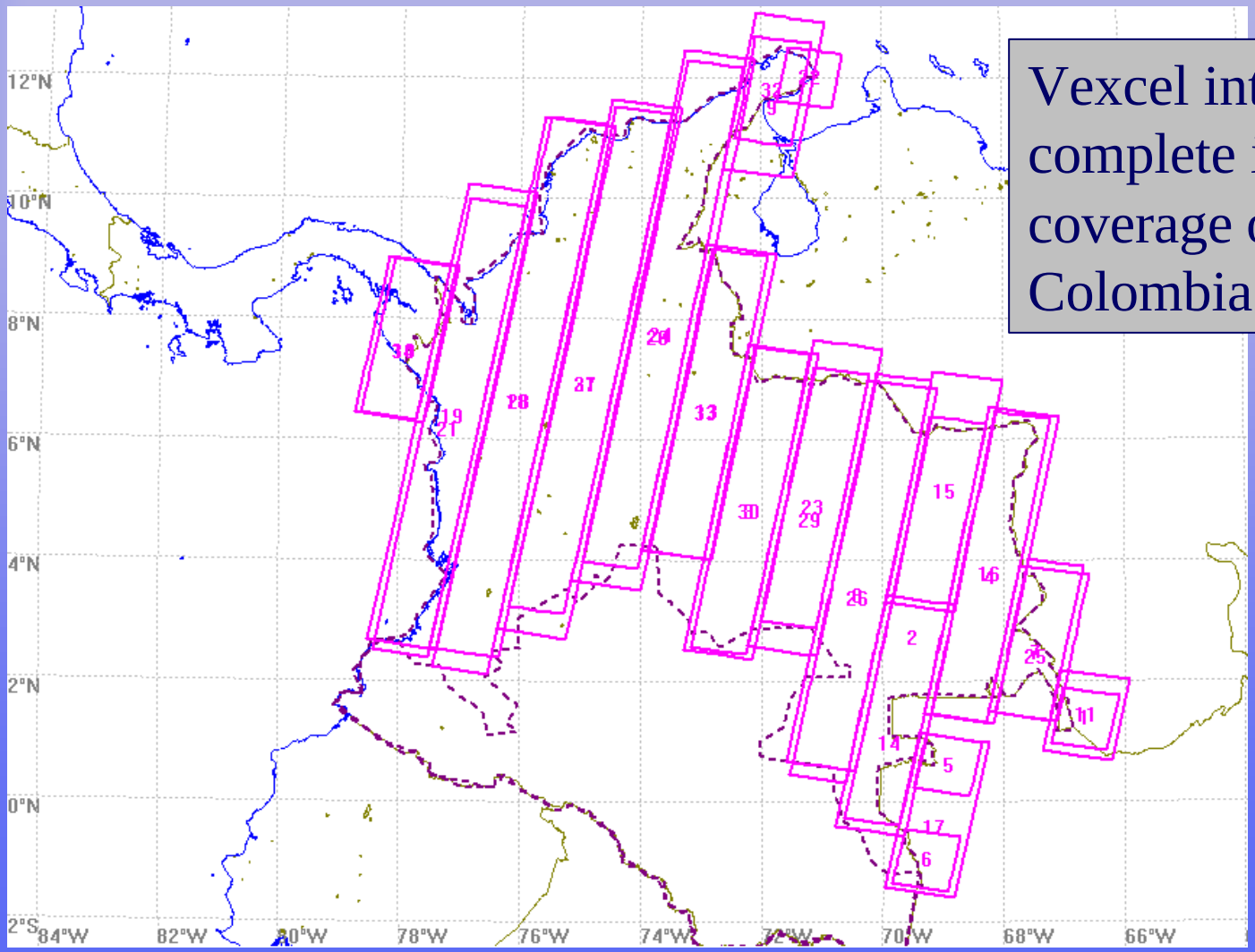
Future Colombia Coverage



Vexcel intends to complete its DEM coverage of Colombia in 2001.

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DEM Merging Algorithm

- Stereo and IFSAR DEM Alignment
  - Remove planimetric displacements between the DEMs.
- Stereo and IFSAR DEM Splicing
  - Piece stereo and IFSAR DEM together to correct stereo DEM errors in flat or feature-less regions.
- Spliced and IFSAR DEM Fusion
  - Combine wavelet transform coefficients of spliced and IFSAR DEM to produce the final merged DEM.

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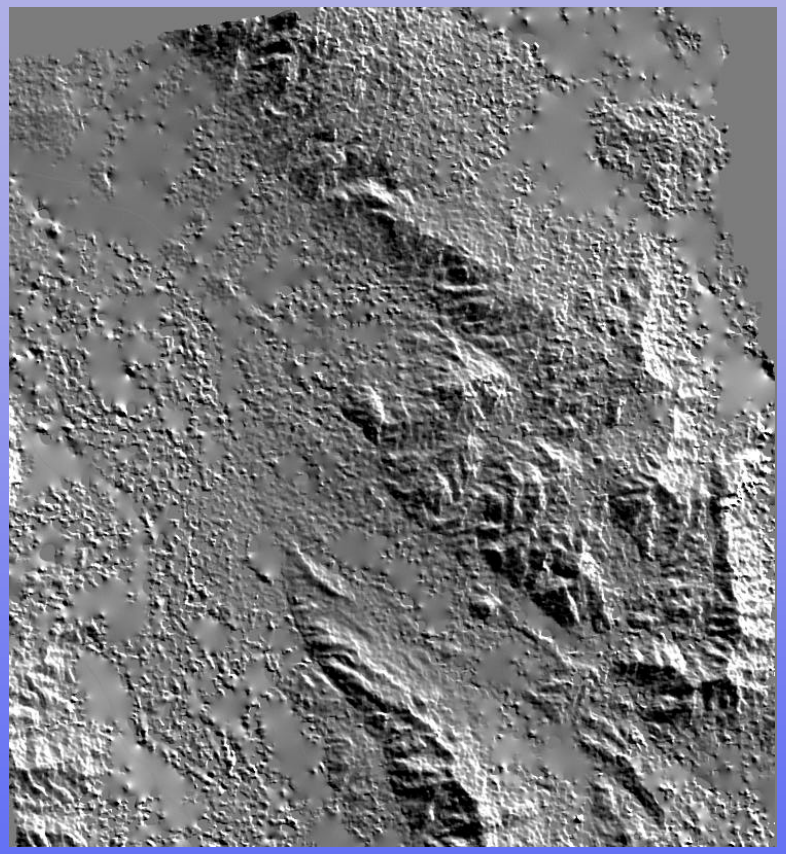
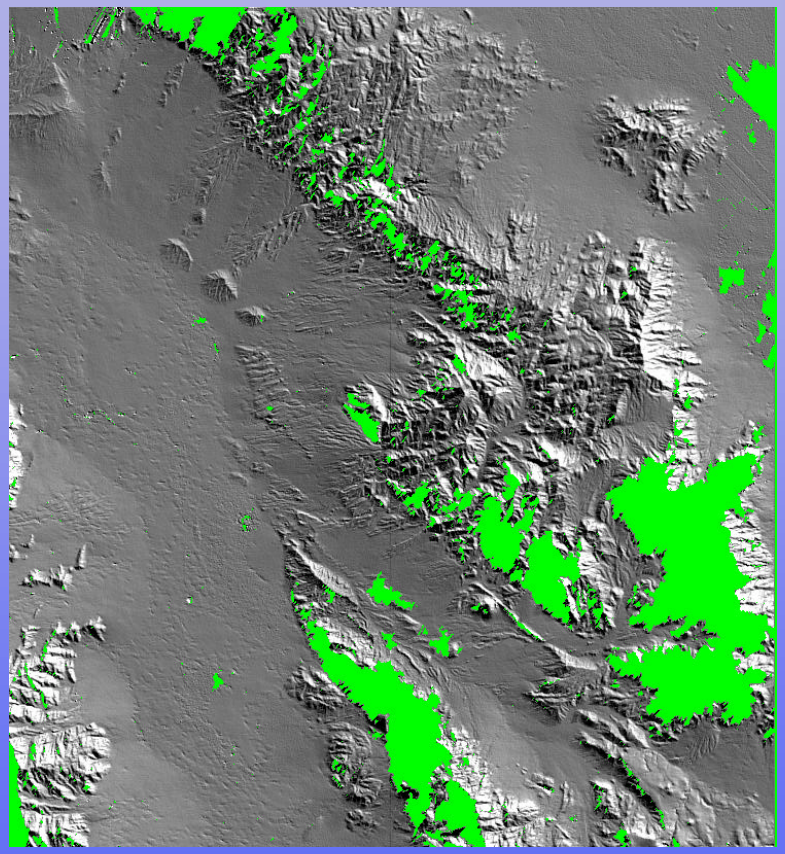
Death Valley DEM Merging



Stereo DEM



IFSAR DEM

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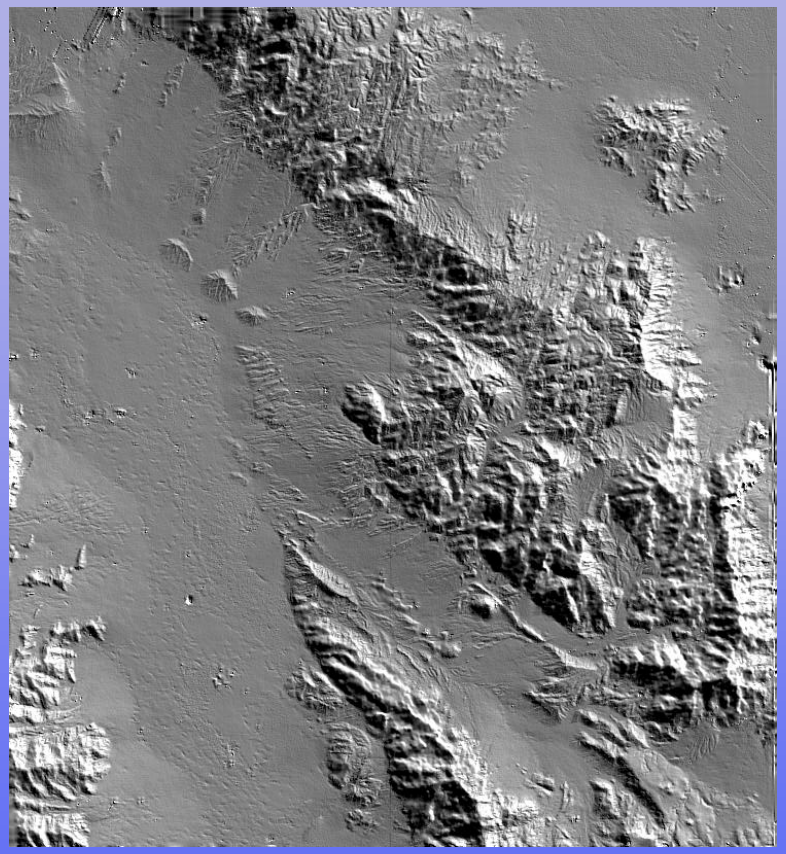
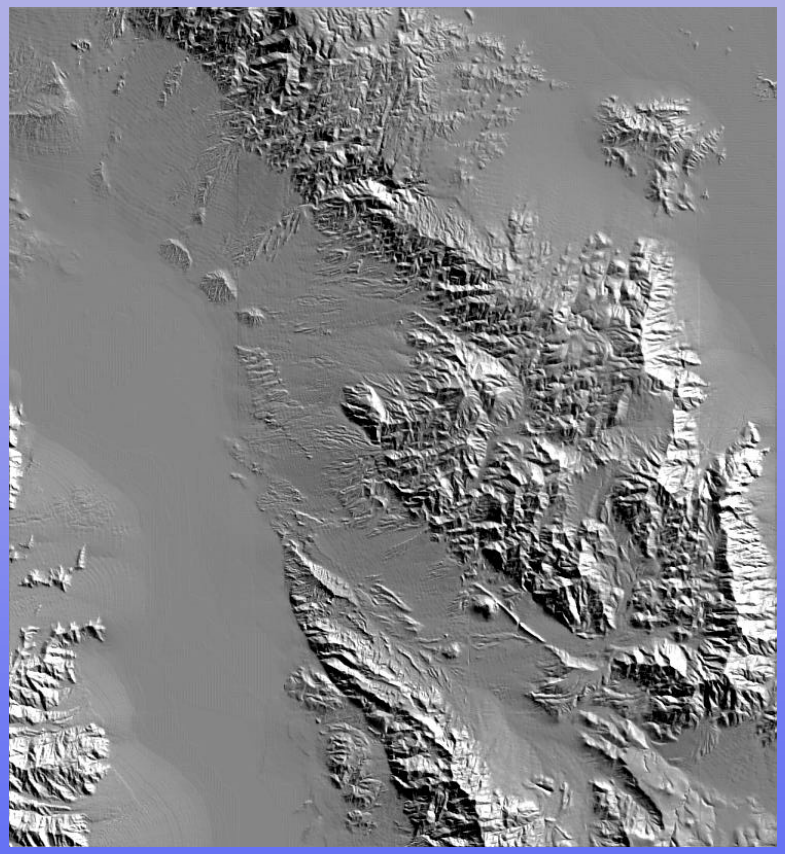
Death Valley Merged DEM



Merged DEM



USGS DEM

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Merging Error Statistics

- **Stereo random errors do not degrade fused results: in fact, fusion is better than IFSAR alone**
- **Splicing and fusion together remove systematic errors if low-order stereo moments are good**

Error Statistics on non-null IFSAR (bootstrapped) postings

	Standard Deviation	Measured LE90
IFSAR (ST)	14.7192	24
Stereo	25.3703	39
Spliced (ST)	14.4628	23
Fused (ST)	14.4477	23

Error Statistics on all postings

	Standard Deviation	Measured LE90
Stereo	26.7619	39
Fused (ST)	17.9842	26
Fused (tilted)	20.1143	30

Error Statistics on non-null IFSAR (tilted) postings

	Standard Deviation	Measured LE90
IFSAR (tilted)	36.0727	57
Stereo	26.0546	39
Spliced (tilted)	31.3275	53
Spliced (ST)	16.0127	24
Fused (tilted)	16.4551	26

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Merging Summary

- Merging combines the best properties of stereo and IFSAR DEMs into a single high-quality DEM.
  - Noisy stereo data in flat regions is replaced by IFSAR data.
  - Dropout in IFSAR data is covered by stereo data.
  - Merged DEM has coarse-scale accuracy of stereo DEM with the fine-scale accuracy of the IFSAR DEM.
- Merging can be done automatically, or hand tuned in difficult cases.
- Phase bootstrapping followed by merging can produce high-quality DEMs over difficult terrain.

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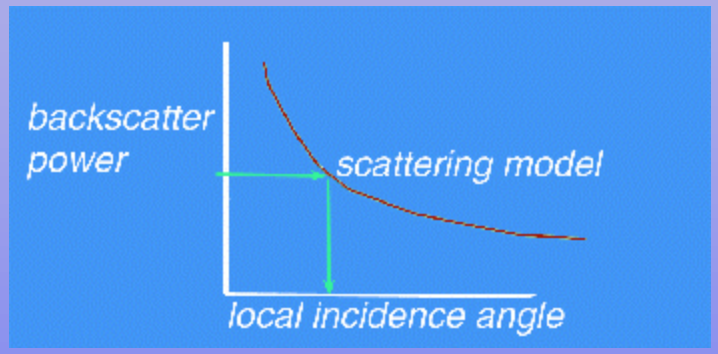
DEM Shape From Shading Radarclinometry

Assume: SAR backscatter is directly related to terrain slope



Given: A SAR image *and* a crude DEM

Goal: To refine DEM detail based on image shading

Trick: Avoid deviating from true shape when assumption violated

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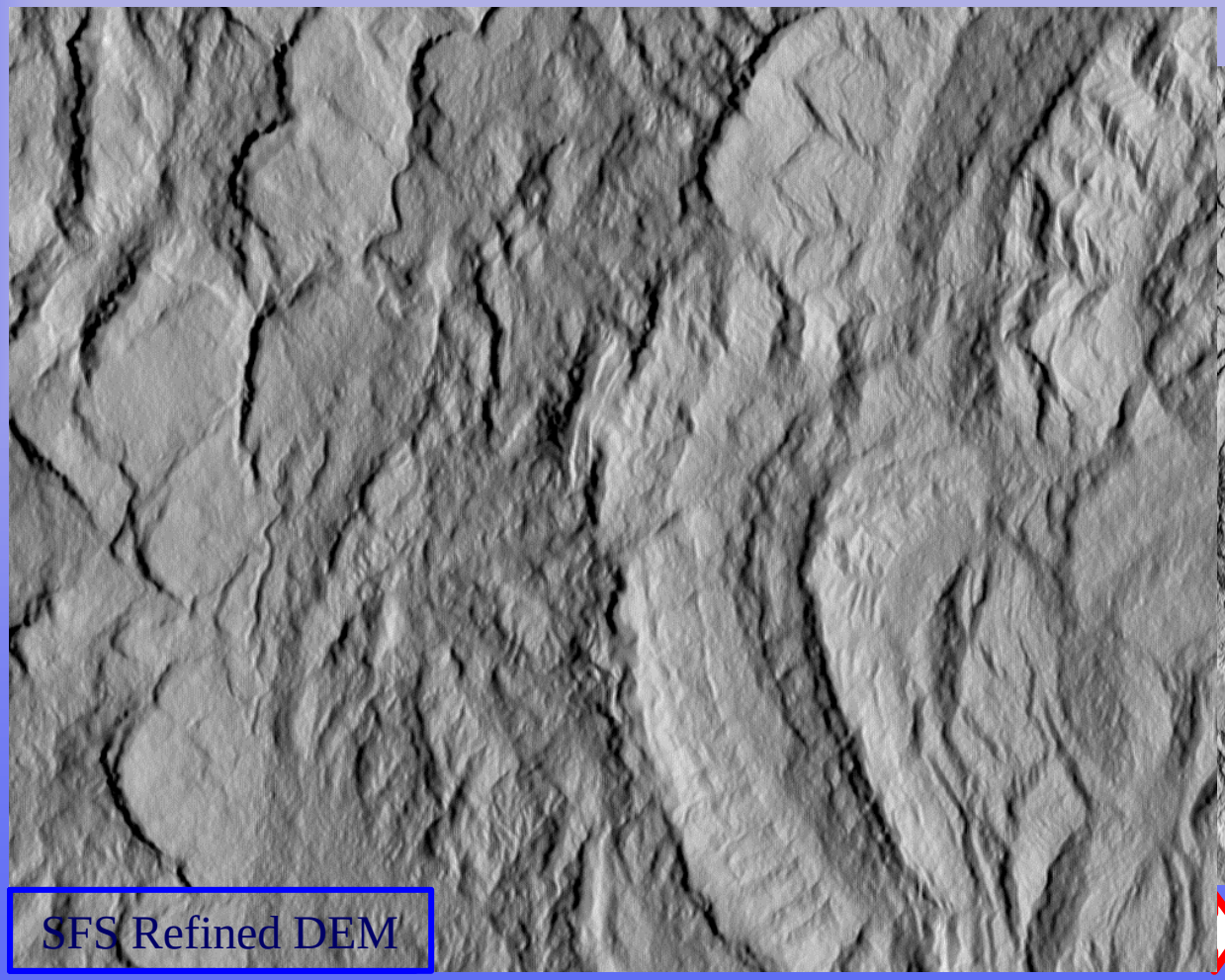
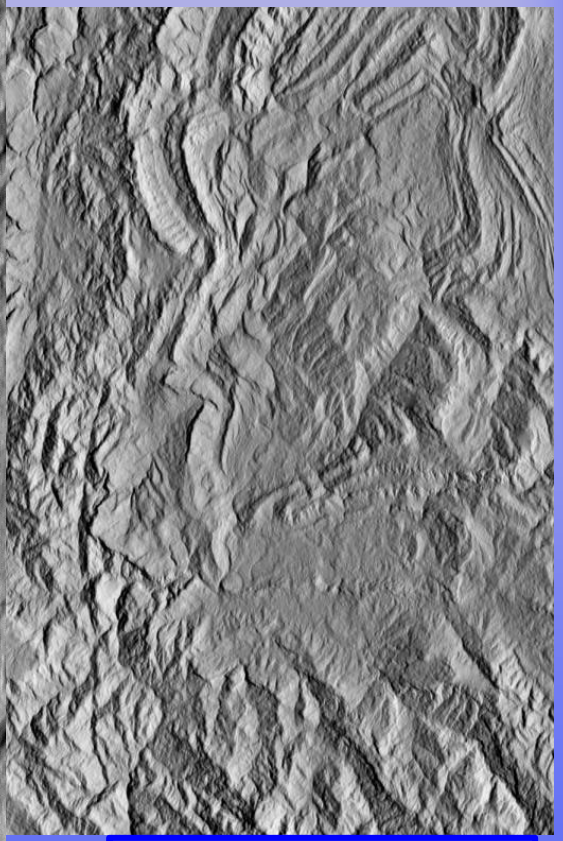
DEM Shape From Shading
Example results



SFS Refined DEM



SFS Refined DEM

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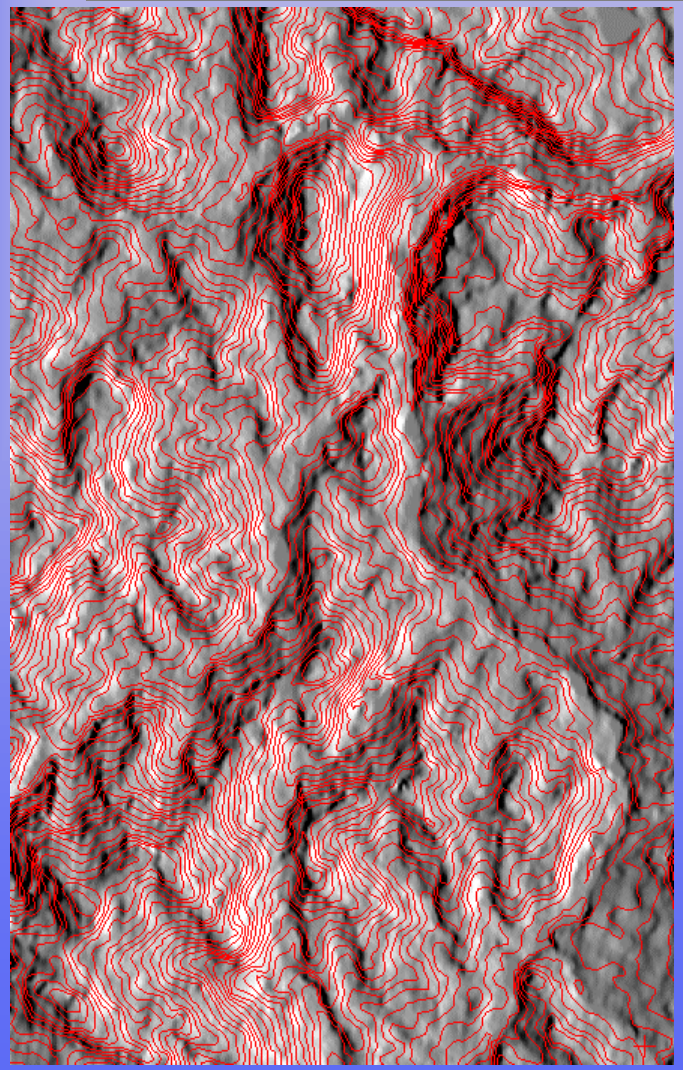
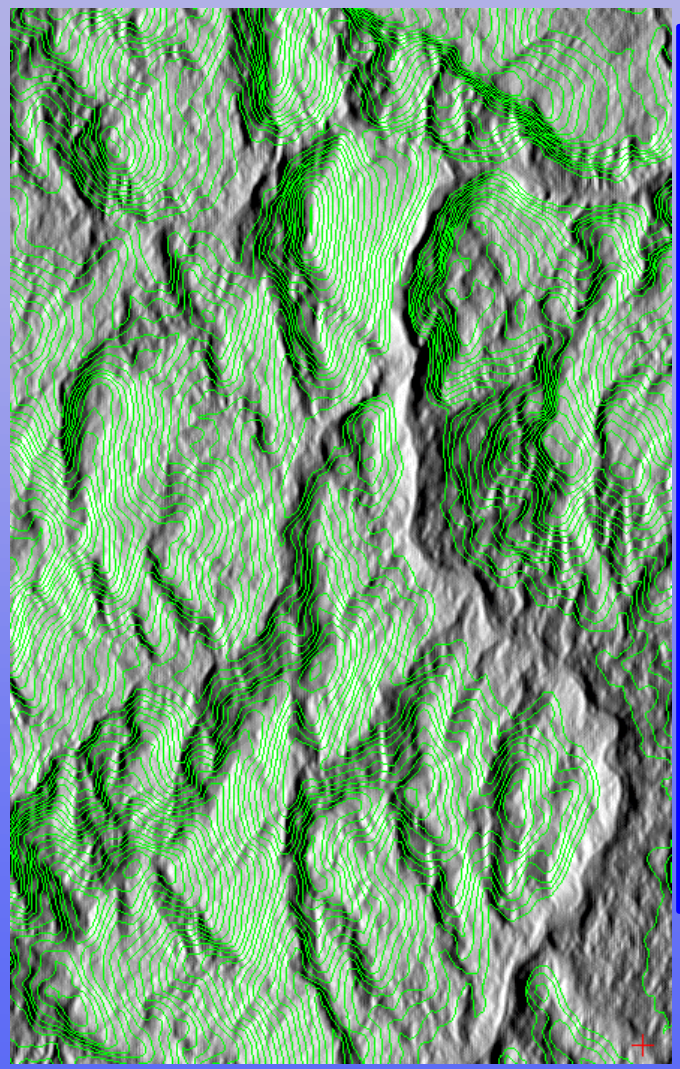
DEM Shape From Shading
Example Contours





- Original contours exhibit artifacts

SFS improved contours contain:

- Better river crossings
- More detail
- Less noise
- 10%-20% improved accuracy

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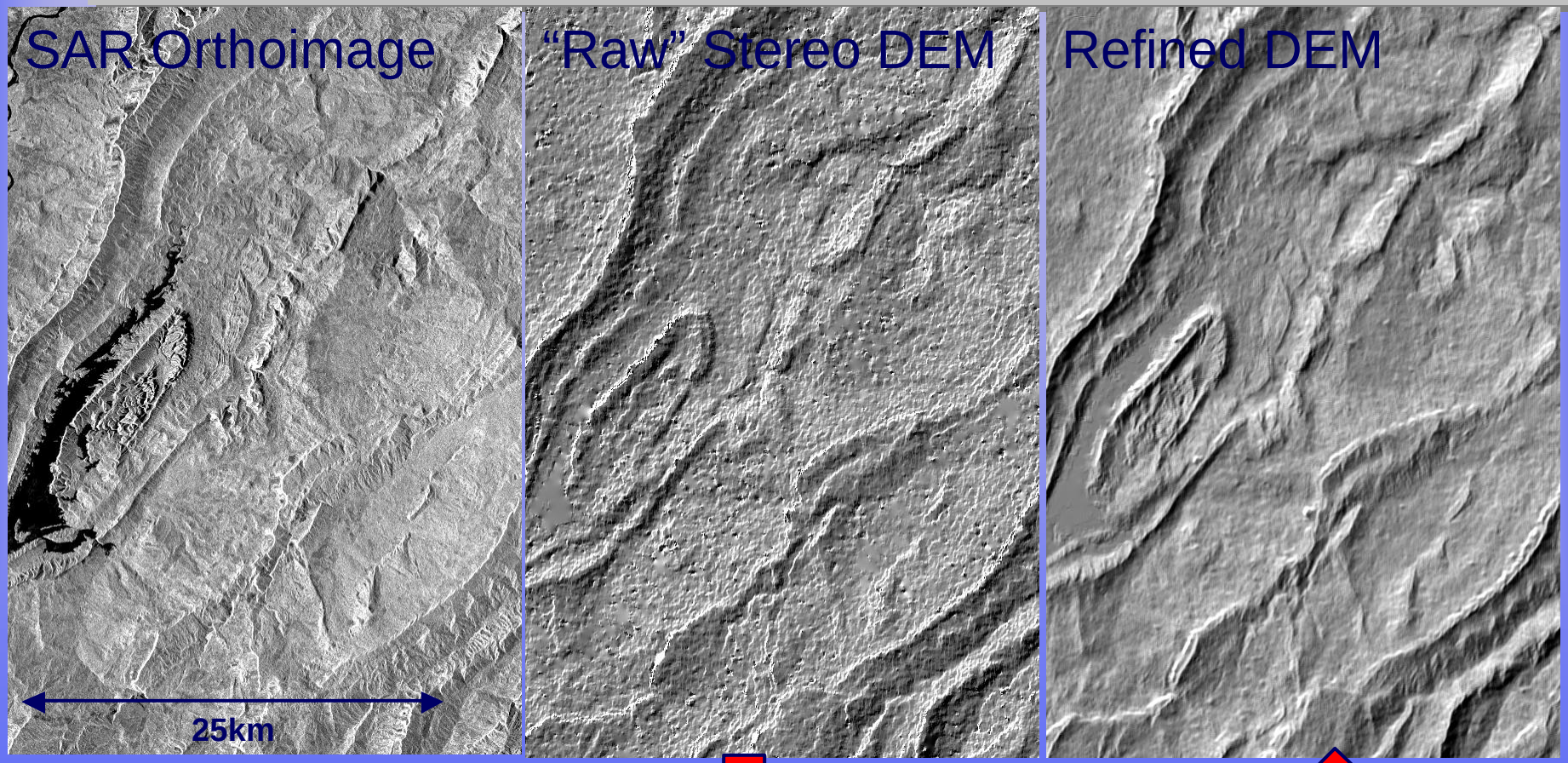
SAR DEM Post Processing



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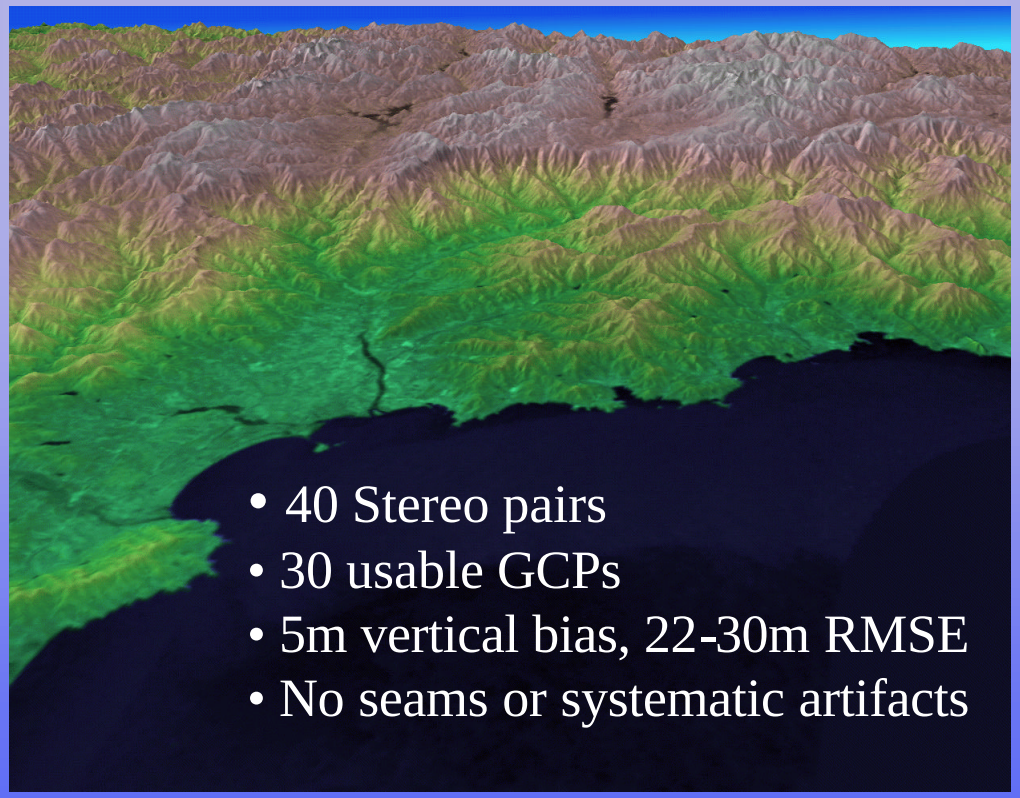
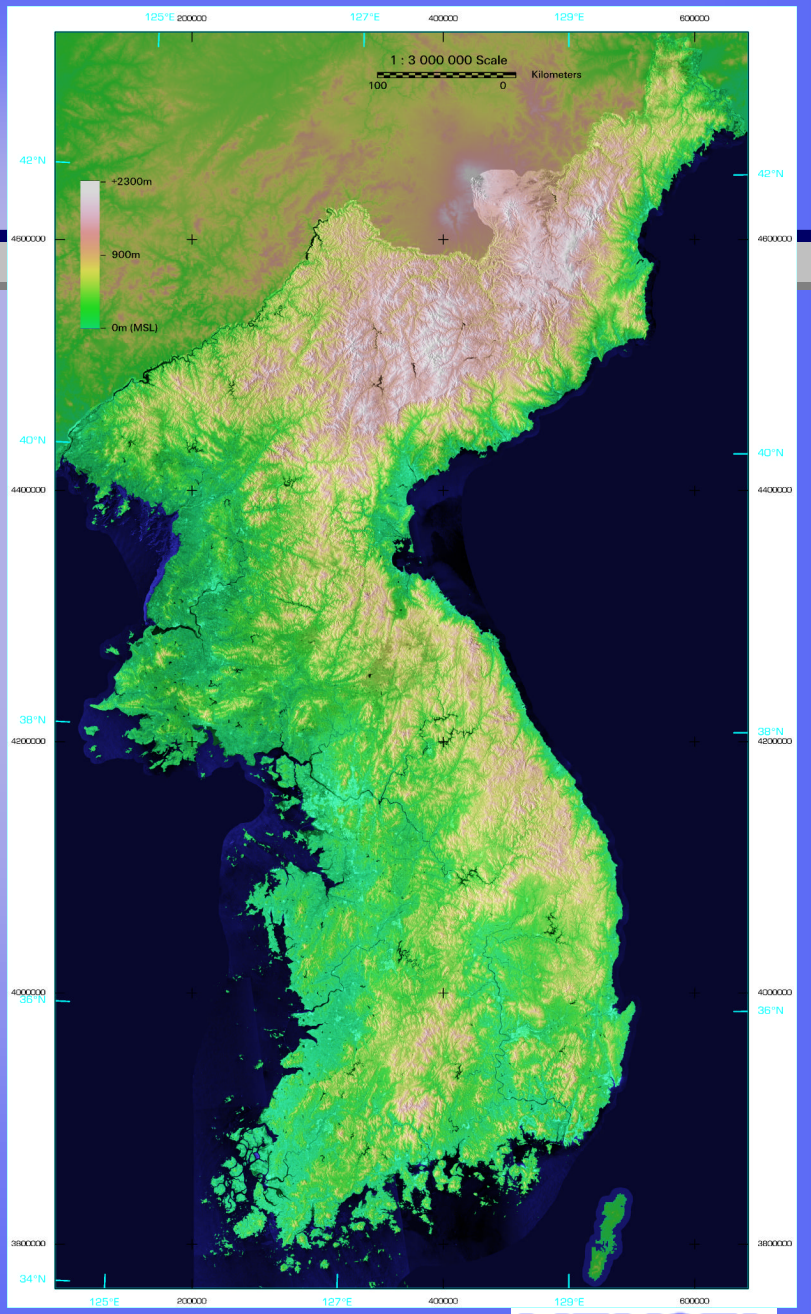
Stereo SAR Korea

Map of North&South Korea from RADARSAT Stereo



- 40 Stereo pairs
- 30 usable GCPs
- 5m vertical bias, 22-30m RMSE
- No seams or systematic artifacts



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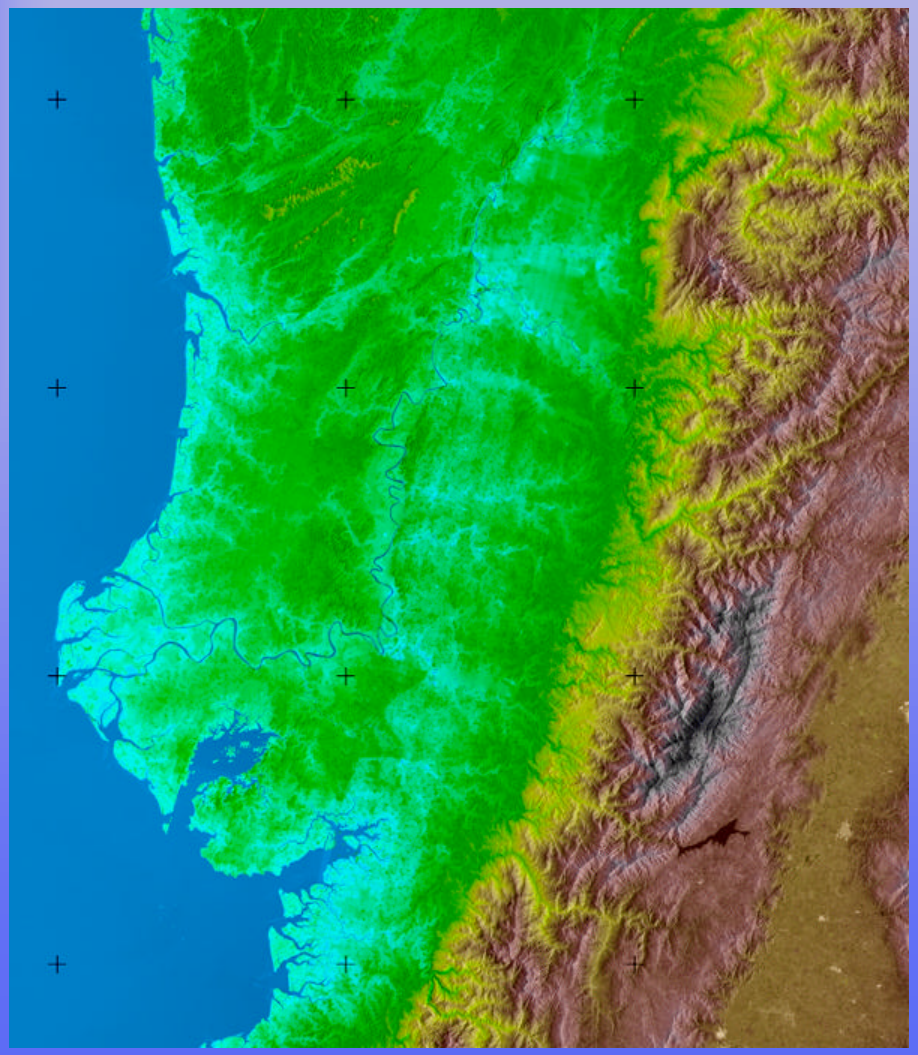
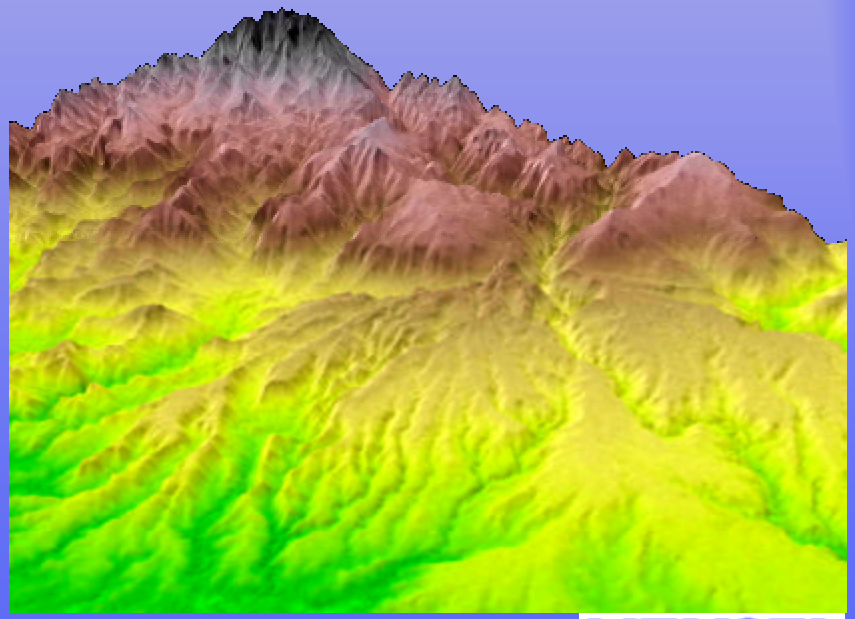
Stereo SAR
Colombia Coast



- Location: Pacific coast of Colombia
- 30 RADARSAT images (standard and wide beam) processed in1998
- 50m post DEM, 20m Ortho-image, 100,000 km^2 area



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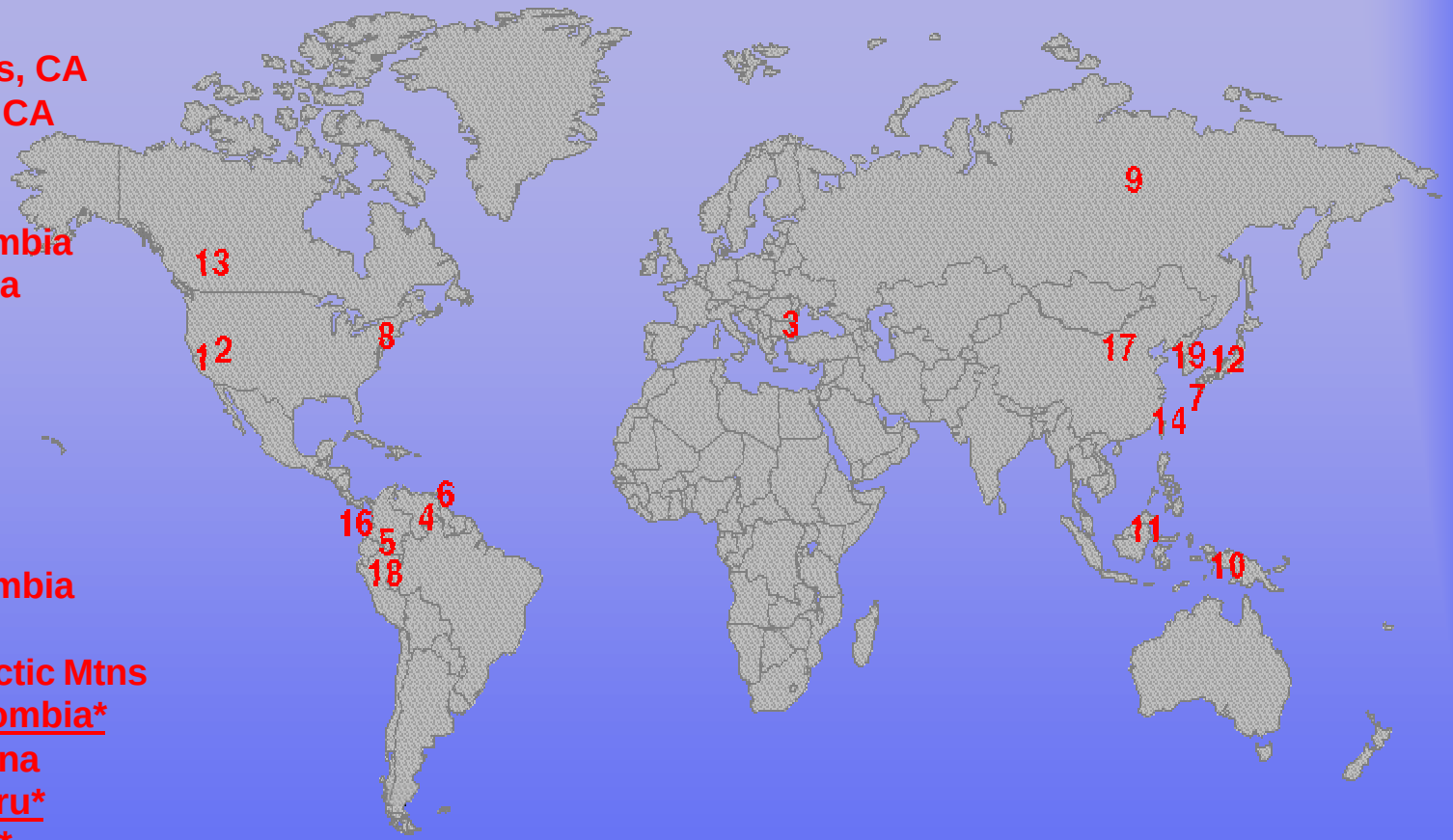
Stereo Project Coverage

1. Camp Roberts, CA
2. Death Valley, CA
3. Tuzla, Bosnia
4. Venezuela
5. Gaitana,Colombia
6. French Guiana
7. Okinawa
8. Virginia
9. Siberia
10. Irian Jaya
11. Kalimantan
12. Nagano
13. British Columbia
14. Taiwan
15. Trans-Antarctic Mtns
16. Coastal Colombia*
17. Hedong, China
18. Northern Peru*
19. N.&S. Korea*
20. South Colombia*



* 90,000 km^2 or more coverage

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SRTM Finishing

Programmatic Summary

- Vexcel teamed with BAE to develop system by Sept ‘01
- Designed to semi-automatically edit and QA JPL products
- Production phase will take 2 years to process 14,000 cells

Technical requirements

- Preliminary screening to quality check JPL results
- Semi-Automated Editing
  - remove spikes/wells in DEM
  - cartographic editing of waterbodies
- Detailed River extraction for FFD (R&D)

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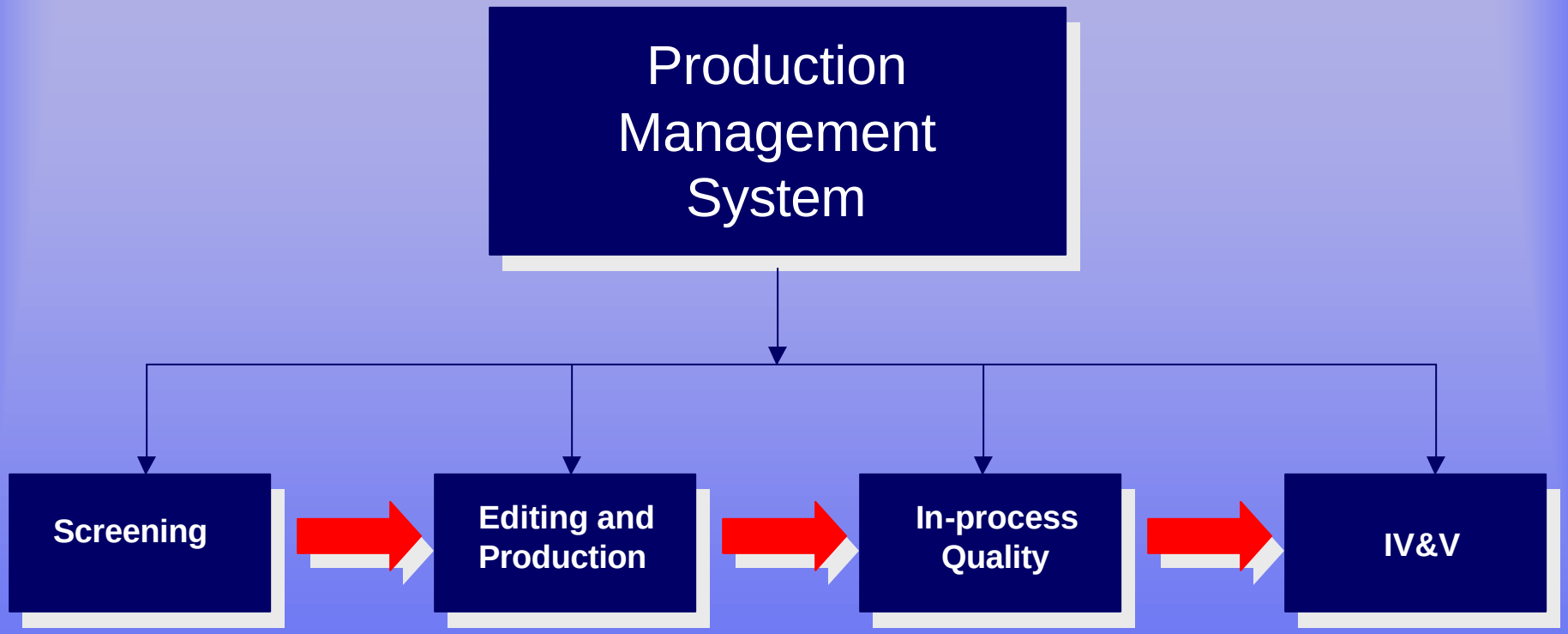
High-Level SRTM Finishing System



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Conclusions

- Stereo SAR DEMs can be reliably generated with minimal control data for large areas
- Further DEM refinements provided by shape from shading
- A priori DEMs (e.g. Stereo) can correct IFSAR biases and allow for improved phase processing
- Combined Stereo/IFSAR techniques can provide DTED-2 beyond SRTM coverage (+60°North)
- Radarsat-1 stereo has been well proven as a fast, reliable source of 25-30m RMSE DEM data
- Radarsat-2 stereo will reduce errors and control requirements considerably

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